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# Experimental study on hydrodynamic performance of arc plate breakwater

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ABSTRACT

The arc plate breakwater, which consists of several arc plates suspended on supporting piles, is proposed in this paper. The wave damping performance of the breakwater is explored by two dimensional regular wave model tests. The hydrodynamic performance of the breakwater is compared with that of the similar breakwater which consists of several horizontal plates. The relative width, relative submergence, relative height, relative gap and the plate amount of the arc plate breakwater those identified with the hydrodynamic performance are discussed. The variation of reflection, transmission and dissipation coefficients alone with the relative width are also presented. It is demonstrated that the performance of the arc plate breakwater is better than that of the horizontal plate breakwater. The transmission coefficient can be reduced to 0.5 when the relative width is about 0.2. The performance relates to the relative submergence, height and gap. Yet the amount of the arc plate has a little influence on the wave attenuation performance.



## 1. Introduction

Breakwaters are mainly applied to provide protection against sea waves attack in coastal engineering, for the purpose of structure shielding, harbour activities and temporary constructions. The size of the breakwaters generally depends on their applications and the level of the required wave attenuation. The breakwaters those protect the port and harbour are usually larger than those protect the marina and bathing beach. Compared with the traditional bottom detect breakwaters, some open type breakwaters attract many researchers attention with the advantage of material saving, cost reducing and free water exchanging. Therefore, the research activities for the hydrodynamics performance of the open type breakwaters are in progress for the prevailing of economical and environmental conditions. And the plate-type breakwater which consists of a single or a combination of multiple plates with different alignments located at various immersion depths in water domain, is proposed as one of the cost-effective and friendly environmental structures. The typical plate-type breakwaters include a single horizontal plate, twin horizontal plates, inclined plate and T-type barrier, etc.

The theoretical studies have been carried out to analyze the wave propagation over a plate structure. It may be found as the earliest work that Stoker (1957) presented a simple set of analytical solutions to determine the reflection and transmission coefficients of long waves propagating over a plate. Ijima et al. (1970) extended Stoker's analysis to cover the whole spectrum of the incident wavelength. For a plate with arbitrary submergence depth, analytical expression of reflection and transmission coefficients for long incident waves were obtained by Siew and Hurley (1977). Using Siew and Hurley's (1977) solution, Patarapanich (1984) analyzed the variation of the reflection coefficient versus the plate length and derived the conditions of maximum and zero reflection. Liu and Iskandarani (1991) applied the method of eigenfunction expansions to derive a semi-analytical solution for short-wave groups over a submerged plate with finite thickness. By the same method, Wang and Shen (1999) analyzed the reflection and transmission coefficient of waves from a group of submerged horizontal plates. The similar study about wave motion over a twin-plate breakwater was carried out by Usha and Gayathri (2005). Cho and Kim (2013) investigated the transmission of oblique waves by a submerged horizontal porous plate by eigenfunction expansion method.

Numerical analysis such as the boundary integral method was introduced to solve the submerged plate problem by Liu and Abbaspour (1982) and also Liu and Iskandarani (1991). The finite element method have also been applied to investigate wave propagation past a submerged plate by Patarapanich and Cheong (1989). Yu and Chwang (1994) applied the boundary-element method to study the performance of a submerged porous plate

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as a breakwater. Wu et al. (2014) simulated the interaction between surface waves and horizontal plates at water surface by FLUENT CFD software using k-omega turbulence model.

The measurements about the reflection and transmission coefficients of waves from a submerged plate were carried out by Patarapanich and Cheong (1989) for validation of their numerical solutions. Neelamani and Rajendran (2002a, 2002b) experimentally investigated the T-type and ⊥-type breakwaters at varying submergence under regular and irregular waves. The experimental studies on the performance of twin-plate and multiple plate breakwater were conducted by Neelamani and Gayathri (2006) and the work for the multiple-plate breakwater are carried out by Wang et al. (2006) respectively. Rao et al. (2009) experimentally explored the wave transmission of a plate at varying inclinations and submergence in regular waves.

The above mentioned investigations are nearly all related to the cases of wave motion over horizontal or vertical plates. The presence of the plate near the water surface tends to steepen the waves over the plate due to the shoaling and some wave energy are dissipated by wave breaking, turbulence and friction on the plate. Since the semicircular breakwater was first developed in Japan in the beginning of the 1990s (Tanimoto and Takahashi, 1994), many research work has been conducted about the hydraulic performance of the semicircular breakwater for the prevailing advantages, such as high stability against sliding, zero overturning moment acting on the caisson as the hydrodynamic pressure acting on the structure surface passes through the centre of the circle, light weight which is suitable for soft soil foundation, and easy for construction and removal (Xie, 1999; Yuan and Tao, 2003). Inspired by the idea of the semicircular breakwater, the arc plate breakwater is proposed in the present study. The arc plate breakwater consists of several arc plates suspended on supporting piles. The hydrodynamics efficiency of the breakwater is explored by physical model tests. The performance of dissipating waves is presented and evaluated by the variation of the reflection, transmission coefficients along with the relative width.

## 2. Physical modeling

### 2.1. Experimental set up

The physical model tests are conducted in the wave flume with 22.00 m in length, 0.60 m in depth, and 0.45 m in width of the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology. The experimental set up is depicted in Fig. 1. There is a wave generator on one side of the flume to generate regular waves in the tests, and on the other side of the flume, there is an energy dissipator with a slope to dissipate the transmitted waves. There are two wave gauges (No. 1 and No. 2) at the sea side to measure the wave surface evaluation. The incident and reflected waves can be separated by the Goda's two point method (Goda and Suzuki, 1976). The same facilities and method are applied at the lee side, thus the reflected waves from the wave flume can be separated, and the reflection influence of the absorber can be eliminated, then the transmission coefficient can be obtained exactly.

### 2.2. Model details

The breakwater model is placed at the middle of the wave flume. The configuration of the arc plate breakwater is illustrated in Fig. 2(a), and the similar horizontal plate breakwater is illustrated in Fig. 2(b). The width of the model alone in the wave propagating direction is denoted by $W$. The height of the arc plate is denoted by $h_a$, and the gap of the two plates is denoted by $d_g$. The radius of the arc plate is denoted by $R_a$. The models are made of organic glass boards, and the thickness of the boards is 0.010 m. There is a small hole in each corner of the plate, and the plates are supported by four screw rods through the holes. Each plate is fixed by the upper and lower screw nuts in the corner, so that the location of the plate can be changed conveniently. The photos of the arc plate breakwater and the horizontal plate models are presented in Fig. 3(a) and (b), respectively. It should be noted that constructing the arc plate breakwater should be more difficult than the horizontal plates in a real sea.

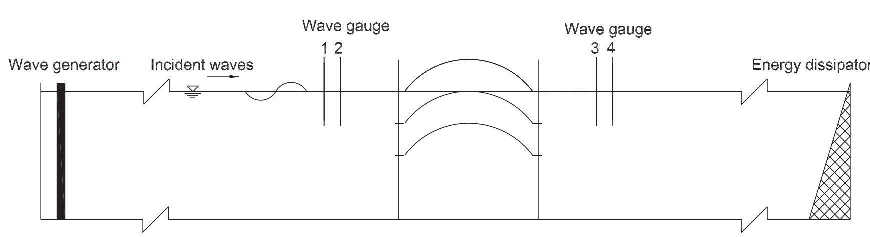


**Fig. 1.** Schematic diagram of experimental set-up.

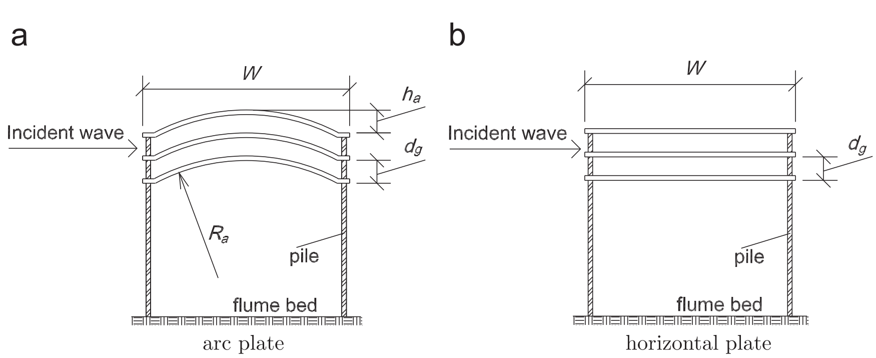


**Fig. 2.** Details of breakwater models. (a) Arc plate. (b) Horizontal plate.